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A METALLURGICAL INVESTIGATION OF TWO LARGE DISCS OF CSA ALLOY

By E. E. Reynolds, J. W. Freeman, and A. E. White
University of Michigan

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SUMMARY

It has been found that the properties of heat-resisting alloys are dependent to a large extent on the conditions of fabrication. Because the large size of certain gas-turbine rotors has introduced fabrication procedures for which information is not available, a research program was begun at the University of Michigan to ascertain the properties of the better alloys in the form of large forgings.

On the basis of prior investigations of bar stock and a large cheese forging, CSA alloy was thought to have promising properties for gas-turbine rotor service. Two cheese forgings were prepared as large discs by the Crucible Steel Company of America from the same heat of CSA alloy. These two discs were heat-treated and hot-cold-worked. They differed only in that one was given an aging treatment following solution treatment and prior to hot-cold-work and the other did not have this intermediate aging. The discs were cut up for experimental purposes, and several radial coupons were supplied to the University of Michigan for investigation for the NACA.

The data obtained on properties at room temperature and 1200° F showed that the aging treatment was beneficial to the rupture properties of CSA alloy, while no effect in tensile, hardness, or time-deformation properties was observed; extrapolation of the rupture data, however, indicates that the beneficial effect of the aging would be lost at time periods of approximately 10,000 hours.

The relation of properties of the discs of CSA alloy with those of bar stock, an as-forged disc, and discs of other alloys depends on the processing procedure and heat treatment as well as on the chemical composition. Because all these varied, direct evaluations of individual factors cannot be made.

INTRODUCTION

The need for improved materials for use in gas-turbine rotor applications has led to the development of several alloys with good high-temperature properties. One of these is CSA alloy[1] which is an iron-base alloy with an analysis of 4 percent manganese, 4 percent nickel, 18 percent chromium, 1.5 percent tungsten, 1.5 percent molybdenum, and 0.5 percent columbium. This composition was developed by the Crucible Steel Company of America in cooperation with the National Advisory Committee for Aeronautics.

This report presents the results of a study of the properties at room temperature and 1200° F of two large discs of CSA alloy. The principal object of this investigation was to determine the level of properties which could be developed in the alloy in the form of large disc forgings. The chemical composition had been modified by increasing the carbon and lowering the columbium contents, a change suggested by previous work for improving strength. In addition the data obtained made it possible to show the effect of an aging treatment following solution treatment and preceding hot-cold-work on the properties of these two otherwise similarly processed discs, to compare these properties with those of a large as-forged disc of CSA alloy previously studied, and to determine the degree to which the properties of bar stock could be reproduced in large forgings.

Room temperature and 1200° F are the two temperatures at which properties of materials have been considered as an indication of their performance as rotors in current jet engines. Satisfactory room-temperature properties are needed to withstand the high stresses existing at low temperatures near the hub. Good properties at 1200° F are believed to be a necessary requirement of material near the rim of the discs.

These discs of CSA alloy are two of a number of discs of various alloys which are being studied. The results obtained from investigations on large discs of CSA, 19-9DL, low-carbon N-155, and Timken alloys are given in references 1 to 6.

This work was conducted at the University of Michigan under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

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[1]The original heats of this alloy were designated as 234-A-5 alloy and were reported under that name. The name has since been changed to CSA alloy.

DESCRIPTION OF DISCS

Information concerning the two discs of high-carbon CSA alloy is summarized as follows:

Manufacturer:

The Crucible Steel Company of America

Heat number:

Induction heat 1X2280

Chemical composition:

Both discs were produced from the same heat. The chemical composition was reported to be the following percentages by the Crucible Steel Company of America:

C	Mn	P	S	Si	Cr	Ni	Mo	W	Cb
0.42	4.47	0.030	0.016	0.41	18.06	5.20	1.30	1.20	0.28

This composition is quite close to the original analysis of the alloy but is considerably higher in carbon and lower in columbium than the disc used for the work of reference 2.

Fabrication procedure:

The following information concerning fabrication of the two discs was supplied by the manufacturer:

The heat was cast into a 15-inch-square ingot, and the ingot was hammer-cogged on a 7-ton hammer to a 9-inch-square billet. Two 290-pound slugs were cut from the billet, heated to 2150° F, and upset and rounded in one heat on a 7-ton hammer to 20-inch-diameter by $3\frac{7}{8}$-inch-thick discs. The finishing temperature was 1650° F. One disc was stamped 5 and the other, 6. The additional heat treatments and details of hot-cold-working on the individual discs are as follows:

Disc 5	Disc 6
(1) Solution-treated at 2050° to 2100° F.	(1) Same as for disc 5.
(2) Air-cooled to room temperature.	(2) Air-cooled to 1400° F and aged 24 hours. Air-cooled to room temperature.
(3) Heated to 1420° F. Hot-cold-worked on 7-ton hammer to $3\frac{1}{2}$ inches thick (approximately 10-percent reduction) to an estimated finishing temperature of 1250° F.	(3) Same as for disc 5.
(4) Stress-relieved at 1200° F for 4 hours and air-cooled.	(4) Same as for disc 5.

The final disc size was 20 inches in diameter by $3\frac{1}{2}$ inches thick. Four radial strips 1 inch wide and $3\frac{1}{2}$ inches thick from each disc were supplied for testing to the University of Michigan.

EXPERIMENTAL PROCEDURE

To evaluate the properties at room temperature and 1200° F of the two CSA alloy discs the following testing program was decided upon:

(1) Tensile tests at room temperature and 1200° F

(2) Rupture tests at 1200° F

(3) Creep tests at 1200° F under a stress of 25,000 psi

(4) Hardness, tensile, and rupture tests to show uniformity of the disc material

(5) Stability studies based on hardness, tensile, and magnetic tests and metallographic examination of the specimens after creep and rupture tests

The major emphasis was placed on the high-temperature properties of radial specimens from near the rims of the discs because the rim is heated to the highest temperatures during service. Data on stress against time for total deformation were obtained from the elongation curves from the rupture and creep tests.

The test specimens were obtained from coupons cut from the discs according to the diagram of figure 1. This drawing shows the location of the specimens and the identifying code. In the code the letters X, Y, and Z refer to locations of the coupons with respect to the faces of the discs. In the tables the specimens designated by a C after the specimen number were from near the center of the disc. All other specimens were from the rim end of the coupons. Tensile and creep tests were conducted on standard 0.505-inch-diameter specimens. The specimens for rupture tests were of 0.160-inch diameter.

RESULTS

Hardness Surveys

There was very little difference in hardness between the two CSA alloy discs. (See figs. 2 and 3 and table I.) Both discs had Brinell hardnesses falling in the general range of 230 to 255, although some of the values were outside this range. The hardness surveys showed that the discs had somewhat higher hardness near the rim than near the center. In general they also were harder near the surface exposed to forging than in the interior. However, the over-all hardnesses of the discs were uniform for forgings of this size.

Short-Time Tensile Properties

The tensile properties at room temperature and 1200° F are presented in table I and the curves of stress against strain are included as figures 4 and 5.

The tensile properties of disc 6, which was aged following solution-treating and preceding hot-cold-working, are only slightly higher than those of disc 5, which was not aged. Average room-temperature 0.02-percent-offset yield strengths of discs 5 and 6 were 47,800 and 50,300 psi, respectively. Both discs had room-temperature tensile-test elongations varying from 15 to 30 percent. The ductility was lowest in the center plane.

At 1200° F both discs had tensile strengths of about 60,000 psi, 0.2-percent-offset yield strengths of 43,000 psi, and elongations of approximately 30 percent.

Rupture Test Characteristics

The rupture test data at 1200° F for the two discs of CSA alloy are given in table II. Included in this table are the estimated ductilities to fracture and the rupture strengths at definite time periods obtained from the logarithmic curves of stress against rupture time of figure 6.

Disc 5, which was not aged before hot-cold-working, had strengths for rupture in 100 and 1000 hours of 37,000 and 31,500 psi. Corresponding strengths for disc 6, which was aged, were 41,000 and 34,000 psi. Comparative ductilities to rupture of the discs were 13-percent elongation to rupture in 1000 hours for disc 5 and 9 percent for disc 6.

Rupture tests on specimens from the three locations designated in table II were run to obtain an indication of the uniformity of rupture properties of the discs. These tests show the relative fracture times of center and rim material under the stress which gave fracture in 100 hours in the series of tests on rim specimens from the center plane of the respective discs. Disc 5 showed no appreciable variation in rupture strength between locations. The specimens from near the center and near the surface of disc 6 gave shorter rupture times than the center-plane radial specimen near the rim. This disc was weakest near the surface at the rim. A more complete survey would have included tangential specimens, but material for such test specimens was not provided.

Time-Deformation Strengths

Only a limited amount of time-deformation data was obtained for the two discs of CSA alloy. These data for both discs have been combined in figure 7 along with data for the as-forged low-carbon CSA alloy disc previously studied. On the basis of one creep test on each disc the properties at the lower deformations and longer time periods appear to be very similar to those of the previously tested low-carbon CSA alloy disc. However, at the higher deformations and shorter time periods the strengths of the hot-cold-worked high-carbon CSA discs are higher than that of the low-carbon CSA disc. The transition curves are also higher for the two high-carbon CSA discs.

The curves of stress against the logarithm of the time for total deformation were plotted from data in table III. These data were taken from the time-elongation data for creep and rupture tests. The stresses to cause the various total deformations in time periods of 1, 10, 100, 1000, and 2000 hours, defined by the curves of stress against time for total deformation, are shown in table IV. Both discs have very similar time-deformation strengths with the stress to cause a total deformation of 0.5 percent in 1000 hours being 25,000 psi.

Creep Strength

Data from time-elongation curves for creep tests, including total deformations in 100, 500, and 1000 hours and creep rates at 500 and 1000 hours, are shown in table V. The minimum creep rates for the rupture tests are given in table II. Minimum creep rates from the rupture tests and the creep rate at 1000 hours for the creep tests are plotted against stress on logarithmic coordinates in figure 8. These curves for discs 5 and 6 are compared in figure 8 with the curve of stress against creep rate for the previously tested large forged disc of low-carbon CSA alloy. Only one creep test was conducted on materials from the two discs, 5 and 6, to furnish comparative data. A creep strength of 23,500 psi for a rate of 0.0001 percent per hour was obtained for both discs. However, on the basis of the curves of figure 8, disc 6, which was aged, appears to be slightly superior to disc 5.

Extrapolation of the transition curves of figure 7 for both discs indicates that the 0.0001-percent-per-hour creep strength of 23,500 psi will be a safe design stress for this material out to time periods of 10,000 hours.

Stability Characteristics

The effect of creep and rupture testing at 1200° F on the room-temperature physical properties, the magnetic susceptibility, and the microstructure of the CSA alloy discs was used to evaluate the stability characteristics of this material.

Both discs had lower room-temperature tensile properties after creep testing and showed a small decrease in Vickers hardness during rupture testing as is shown by the test data of table VI. There was no appreciable change in magnetic susceptibility during the rupture testing of either disc.

Photomicrographs of the original material and completed-rupture-test specimens are shown in figures 9 to 11. Original microstructures are representative of the structure near the rim and near the center of the discs. There was considerable variation in grain size between the discs and from the rim to center of the individual discs. Disc 5 varied in grain size from 7 at the rim to 4 near the center. Disc 6 varied from 5 at the rim to 2 to 4 near the center.

Considerably more excess constituent was present in the structure near the centers of both discs than near the rim. This excess constituent appeared as larger and more agglomerated particles near the center. The aged disc 6 showed evidence in a very fine precipitate. No apparent change occurred in the microstructures of the discs during rupture testing.

DISCUSSION OF RESULTS

The properties of the two discs considered in this investigation are summarized in table VII and compared with the properties of an as-forged disc previously investigated. These three CSA alloy discs had 0.02-percent-offset yield strengths ranging from 40,000 to 50,000 psi at room temperature. The stress for rupture in 100 hours at 1200° F ranged from 35,500 to 41,000 psi, and for 1000 hours from 30,000 to 34,000 psi. The ductility of the specimens tested was good.

Test material was not available for the determination of the ductility at the exact centers of the discs. Low center ductility has been a serious problem in most rotor forgings. The testing program on CSA alloy has been restricted to pancake-type forgings and has not included a contour forging. Such physical tests as have been made on the pancake forgings have not disclosed any outstanding nonuniformity.

In the previous report on a large forged disc of CSA alloy it was recommended that improvement in properties of the alloy could be gained by changing the columbium-to-carbon ratio and, more important, by introducing hot-cold-work into the fabrication of the discs. (See reference 2.) The two CSA alloy discs of the present report had these improvements incorporated in their manufacture. Specifically, the carbon content was raised and the columbium content was lowered, and both discs were hot-cold-worked approximately 10 percent between 1420° and 1250° F.

In general the hot-cold-working and composition change of the two high-carbon CSA alloy discs did not result in an outstanding improvement in properties. The tensile properties were somewhat higher and the rupture strengths slightly higher. Time-deformation strengths were improved for time periods up to 100 hours at high rates of deformation. No appreciable difference between the three discs was observed in creep tests at 25,000 psi. There is some indication that the aging treatment prior to hot-cold-work was of benefit to rupture strength. Extrapolation of the curves of stress against rupture time to longer time periods, however, indicates that the beneficial effect of aging prior to hot-cold-work would disappear at about 10,000 hours.

The low-carbon CSA disc was found to be very stable structurally at 1200° F. This was also true for the two high-carbon CSA discs as indicated by the microstructure, hardness, and magnetic studies. Although the decrease in tensile properties during creep testing is an indication of some instability in the alloy, it has been observed, in general, that hot-cold-worked alloys show a drop in tensile properties as an effect of creep testing. This is probably the result of the strain relief of the cold-worked structure which occurs during the long time at 1200° F.

On the basis of original microstructures the discs were not uniform. There were larger grains and more and larger particles of excess constituents near the centers than near the rims. Neither the data from this investigation nor preliminary experiments on billet stock indicate that this structural condition has an appreciable effect on rupture-test properties at 1200° F.

In general the comparative data for CSA alloy bar stock in table VIII show higher tensile properties and 100-hour rupture strengths than the large discs. The agreement in 1000-hour rupture strengths is quite good. Presumably the higher short-time properties and hardness of bar stock are due to their lower temperature of hot-cold-working. The rupture test ductility of the solution-treated and hot-cold-worked disc was much better than that of similarly processed bar stock. It seems probable, from bar-stock data, that raising the solution-treating temperature on the disc material would produce low rupture test ductility.

The two CSA alloy discs had slightly lower rupture and tensile properties than discs of 19-9DL and Timken alloys but were much weaker than a low-carbon N-155 alloy disc. (See table VIII.) However, the discs of the different alloys cannot be compared on the basis of composition alone because the properties of these alloys vary with production procedure. Variations in heat treatment and hot-cold-working conditions make it impossible to show an exact relationship between composition and properties.

In appraising the data in this report, consideration should be given to the fact that reproducing these properties in other discs depends on the control exercised in production. Also, the properties of the CSA alloy discs would be expected to lose the beneficial effects of hot-cold-work if the test temperature were increased much above 1200° F.

CONCLUSIONS

Sufficient tests have been made to indicate the relative properties of two large cheese-type forged discs of CSA alloy. The chemical composition of the two discs was modified from previous heats of the alloy. Both discs were solution-treated and hot-cold-worked and one was aged prior to hot-cold-work. The following conclusions are indicated by the data:

1. The properties obtained were only slightly better than were previously obtained for an as-forged cheese forging having lower carbon and higher columbium contents. Direct evaluation of the two procedures or the composition change cannot be made because the relative degree of hot-cold-work and prior heat treatment of the as-forged disc is not known.

2. An aging treatment at 1400° F following solution treatment and prior to hot-cold-work was beneficial to the rupture properties of CSA alloy, while no effect was observed in tensile, hardness, or time-deformation properties.

3. Extrapolation of the rupture data indicates that the beneficial effect of the aging would be lost at time periods of approximately 10,000 hours.

4. The large discs had good uniformity. Although the size and amount of excess constituent varied from rim to center of the disc, no adverse effect on properties was observed.

5. The data do not permit an evaluation of the room-temperature properties in the exact center of the discs.

6. In general the tensile properties and short-time rupture strengths of the discs were lower than those obtained from similarly processed bar stock. The 1000-hour strengths agreed quite well. The difference was probably due to the bar stock being hot-cold-worked at the lower temperature of 1200° F.

7. The tensile and 100-hour rupture-strength properties of the two CSA alloy discs were, in general, slightly lower than those of discs of other alloys. On the basis of 1000-hour strengths, agreement between the alloys was satisfactory with the exception of the low-carbon N-155 disc which had higher properties. However, a strict comparison between the discs cannot be made on the basis of composition alone because the production procedures used for these discs were considerably different.

University of Michigan
Ann Arbor, Mich., March 17, 1947

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TABLE I

SHORT-TIME TENSILE PROPERTIES OF LARGE DISCS OF CSA ALLOY

Disc	Specimen number	Specimen location (1)	Temperature (°F)	Tensile strength (psi)	Offset yield strength (psi)			Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)	Brinell hardness
					0.02 percent	0.1 percent	0.2 percent				
5 (Solution-treated; hot-cold-worked)	5BY	CRR	Room	123,000	46,500	59,000	64,500	27,500	15	14.8	---
	5GX	SRR	Room	129,250	50,000	60,000	64,500	33,500	25.5	21.4	247
	5EX	SRR	Room	132,500	47,000	57,500	63,000	35,000	29.5	28.5	226
	5GY-C	CRC	Room	115,500	45,000	55,500	61,000	22,500	16	16.3	241
	5GY	CRR	1200	59,375	------	43,500	46,300	22,500	29	39.1	---
	5BX	SRR	1200	58,125	------	39,500	42,500	20,000	34	53.4	---
	5BY-C	CRC	1200	58,375	------	38,500	41,000	17,500	29	41.9	---
6 (Solution-treated; aged; hot-cold-worked)	6EY	CRR	Room	115,000	53,500	65,000	69,500	32,500	13	10.0	---
	6EX	SRR	Room	130,750	50,000	62,000	68,000	30,000	26	23.9	256
	6GX	SRR	Room	130,000	47,500	64,500	70,500	30,000	27.5	26.8	257
	6EY-C	CRC	Room	117,500	47,000	63,000	67,000	30,000	17	16.6	232
	6BX	SRR	1200	60,875	------	41,000	43,500	22,500	28	44.2	---
	6DZ	SRR	1200	59,500	------	41,000	45,000	22,500	34	47.2	---
	6BY-C	CRC	1200	61,000	------	38,000	41,000	17,500	26	33.5	---

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[1]CRR center-plane radial specimen near rim of disc.

SRR surface-plane radial specimen near rim of disc.

CRC center-plane radial specimen near center of disc.

TABLE II

RUPTURE-TEST CHARACTERISTICS AT 1200° F OF LARGE DISCS OF CSA ALLOY

Disc	Specimen number	Specimen location (1)	Stress (psi)	Rupture time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)	Minimum creep rate (percent/hr)
5 (Solution-treated; hot-cold-worked)	5DY	CRR	40,000	41	39	51.5	------
	5DY	CRR	35,000	252	20	35.6	0.0180
	5DY	CRR	32,000	495	13	30.8	.0105
	5DY	CRR	30,000	3037	10	16.5	.0012
	5DX	SRR	37,000	78	26	60.9	------
	5DX	SRR	37,000	115	24	56.9	------
	5DY-C	CRC	37,000	74	23	42.7	------
	5DY-C	CRC	37,000	112	24	52.8	------
6 (Solution-treated; aged; hot-cold-worked)	6GY	CRR	43,000	80	17	25.6	------
	6GY	CRR	41,000	90.5	24	46.5	------
	6GY	CRR	40,000	534	15	30.8	.0080
	6BY	CRR	38,000	180	18	29.8	.0240
	6BY	CRR	34,000	908	9	14.0	.0035
	6DX	SRR	41,000	28	19	51.9	------
	6DX	SRR	41,000	14	16	57.8	------
	6DY-C	CRC	41,000	43	18.5	31.9	------
	6DY-C	CRC	41,000	67	20	31.9	------

Rupture strength

Disc	Specimen location (1)	Stress (psi) for rupture in -			
		10 hr	100 hr	1000 hr	2000 hr
5	CRR	45,000	37,000	31,500	30,500
6	CRR	------	41,000	34,000	32,000

Rupture ductility

Disc	Specimen location (1)	Estimated elongation (percent) to rupture in -			
		10 hr	100 hr	1000 hr	2000 hr
5	CRR	40	25	13	10
6	CRR	--	24	9	--

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[1]CRR center-plane radial specimen near rim of disc.

SRR surface-plane radial specimen near rim of disc.

CRC center-plane radial specimen near center of disc.

TABLE III

TIME-DEFORMATION DATA AT 1200° F FOR LARGE DISCS OF CSA ALLOY

Disc	Specimen number	Stress (psi)	Initial deformation (percent)	Time (hr) for total deformations of -					Transition to third-stage creep	
				0.2 percent	0.5 percent	1 percent	2 percent	5 percent	Time (hr)	Deformation (percent)
5	5EY	25,000	0.142	5	828	[a]3470	---	----	----	---
(Solution-	5DY	30,000	.15	[b]1	35	152	960	2700	2350	4.0
treated;	5DY	32,000	.16	-	12	50	155	380	295	3.5
hot-cold-	5DY	35,000	.18	-	[b]4	30	88	182	135	2.9
worked)	5DY	40,000	.33	-	---	----	---	----	----	---
6	6DY	25,000	.155	5	960	[a]4550	---	----	----	---
(Solution-	6BY	34,000	.225	-	8	42	305	812	470	2.6
treated;	6BY	38,000	.30	-	---	13	45	117	70	2.5
aged;	6GY	40,000	.36	-	---	17	76	385	350	4.5
hot-cold-	6GY	41,000	.42	-	---	----	---	----	----	---
worked)	6GY	43,000	.50	-	---	----	---	----	----	---

[a]By extrapolation of creep curve.

[b]Estimated.

TABLE IV

TIME-DEFORMATION STRENGTHS AT 1200° F OF LARGE DISCS OF CSA ALLOY

Disc	Total deformation (percent)	Stress (psi) to cause total deformation in -				
		1 hr	10 hr	100 hr	1000 hr	2000 hr
5	0.2	[a]30,000	25,000	------	------	------
	.5	[a]38,500	33,000	27,500	25,000	[a]23,500
	1.0	------	[a]40,000	30,500	26,500	[a]25,500
	Transition	------	------	36,000	30,500	30,000
6	.2	------	25,000	------	------	------
	.5	[a]38,500	33,000	27,500	25,000	[a]23,500
	1.0	------	[a]40,000	30,500	26,500	[a]25,500
	Transition	------	------	38,500	32,000	------

[a]Estimated.

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TABLE V

CREEP TEST DATA AT 1200° F FOR LARGE DISCS OF CSA ALLOY

Disc	Creep test conditions		Initial deformation (percent)	Total deformation (percent) at -			Creep rate (percent/hr) at -	
	Stress (psi)	Duration (hr)		100 hr	500 hr	1000 hr	500 hr	1000 hr
5	25,000	959	0.0142	0.297	0.423	0.530	0.00025	0.00019
6	25,000	960	.0155	.300	.419	.505	.00025	.00014

TABLE VI

EFFECT OF CREEP AND RUPTURE TESTING AT 1200° F ON THE ROOM-TEMPERATURE PHYSICAL

PROPERTIES OF LARGE DISCS OF CSA ALLOY

Disc	Specimen number	Prior testing conditions			Residual room-temperature properties							
		Type test	Stress (psi)	Time (hr)	Tensile strength (psi)	Offset yield strength (psi) 0.02 percent	0.1 percent	0.2 percent	Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)	Vickers hardness
5	(a)	(b)	(b)	(b)	126,250	47,800	58,800	64,000	32,000	23	21.6	[c]261 [d]263
	5EY	Creep	25,000	959	121,000	37,000	48,500	54,000	22,500	[e]19	13.4	---
	5DY	Rupture	30,000	3037	--------	-------	------	------	------	--	----	245
6	(a)	(b)	(b)	(b)	125,250	50,300	63,800	69,300	30,800	22	20.2	[c]270 [d]251
	6DY	Creep	25,000	960	115,000	38,500	50,500	56,000	22,500	[e]14	9.4	---
	6BY	Rupture	34,000	908	--------	-------	------	------	-------	--	----	258

[a]Average of tests on center and surface plane specimens at rim of disc.

[b]Original condition.

[c]Center rim.

[d]Center.

[e]Specimen fractured in gage mark.

TABLE VII

COMPARATIVE PROPERTIES OF THREE CSA ALLOY DISCS

Disc	5	6	Low-carbon CSA (a)
Heat number	1X2280	1X2280	1X2218
Chemical composition, percent:			
C	0.42	0.42	0.25
Mn	4.47	4.47	4.14
Si	.41	.41	.25
Cr	18.06	18.06	18.32
Ni	5.20	5.20	5.76
Mo	1.30	1.30	1.46
W	1.20	1.20	1.51
Cb	.28	.28	.95
Fabrication	Hot-forged; 2100° F, air-cooled; 10 percent hot-cold-work at 1420° to 1250° F; 1200° F, air-cooled.	Hot-forged; 2100° F, air-cooled to 1400° F; 24 hr at 1400° F; 10 percent hot-cold-work at 1420° to 1250° F; 1200° F, air-cooled.	Forged from 2150° F to 1400° F; 1200° F, air-cooled.
Principal Brinell hardness range	230-255	230-255	200-230
Room-temperature tensile properties[b]:			
Tensile strength, psi	126,250	125,250	107,400
0.02-percent-offset yield strength, psi	47,800	50,300	40,300
0.1-percent-offset yield strength, psi	58,800	63,800	53,170
0.2-percent-offset yield strength, psi	64,000	69,300	58,300
Elongation, percent in 2 in.	23	22	35
Reduction of area, percent	21.6	20.2	39.8
Tensile properties at 1200° F[b]:			
Tensile strength, psi	58,625	60,500	51,875
0.2-percent-offset yield strength, psi	43,300	43,200	40,000
Elongation, percent in 2 in.	31	29	27
Reduction of area, percent	44.8	41.6	49.5
Rupture characteristics at 1200° F:			
100-hr rupture strength, psi	37,000	41,000	35,500
100-hr rupture elongation, percent in 1 in.	25	24	32
1000-hr rupture strength, psi	31,500	34,000	30,000
1000-hr rupture elongation, percent in 1 in.	13	9	18
Time-deformation strengths at 1200° F, psi:			
0.2 percent in 10 hr	25,000	25,000	25,000
0.2 percent in 100 hr	------	------	21,000
0.2 percent in 1000 hr	------	------	17,000
0.5 percent in 10 hr	33,000	33,000	30,000
0.5 percent in 100 hr	27,500	27,500	27,500
0.5 percent in 1000 hr	25,000	25,000	25,000
1 percent in 10 hr	[c]40,000	[c]40,000	33,500
1 percent in 100 hr	30,500	30,500	30,000
1 percent in 1000 hr	26,500	26,500	26,500
Transition in 100 hr	36,000	38,500	32,000
Transition in 1000 hr	30,500	32,000	26,000
Creep strength at 1200° F, psi:			
0.00001 percent/hr	------	------	9,000
0.0001 percent/hr	[c]23,500	[c]23,500	21,000

[a]Data from reference 2.
[b]Average values for radial specimens.
[c]Estimated.

TABLE VIII

COMPARATIVE PROPERTIES OF DISCS AND BAR STOCK OF CSA ALLOY AND DISCS OF 19-9DL, LOW-CARBON N-155, AND TIMKEN ALLOYS

Alloy	Form	Heat number (b)	Processing (a): Heat treatment: Temperature (°F)	Heat treatment: Time (hr)	Heat treatment: Cooling (c)	Heat treatment: Aging: Temperature (°F)	Heat treatment: Aging: Time (hr)	Hot-cold-work: Temperature (°F)	Hot-cold-work: Reduction (percent)	Room-temperature physical properties: Tensile strength (psi)	0.02-percent-offset yield strength (psi)	Elongation (percent)	Brinell hardness	Rupture properties at 1200° F for - 100 hr: Strength (psi)	100 hr: Elongation (percent)	1000 hr: Strength (psi)	1000 hr: Elongation (percent)
High-carbon CSA	Disc 5	1X2280	2100	(d)	A.C.	----	--	1420 to 1250	10	126,250	47,800	23	230-255	37,000	25	31,500	13
High-carbon CSA	Disc 6	1X2280	2100	(d)	A.C. to 1400° F	1400	24	1420 to 1250	10	125,250	50,300	22	230-255	41,000	24	34,000	9
Low-carbon CSA[e]	Disc	1X2218	(f)	(f)	(f)	----	--	----	---	107,400	40,300	35	200-230	35,500	32	30,000	18
CSA[g]	Bar stock	3678A2	(h)	(h)	(h)	----	--	----	---	130,500	44,000	25	248	48,000	20	37,000	16
CSA[g]	Bar stock	3678A2	2200	1	W.Q.	----	--	1200	10	147,750	87,250	34	306	46,000	1	42,000	2
CSA[g]	Bar stock	3678A2	2050	2	W.Q.	----	--	1200	10	146,250	83,600	28	314	56,000	5	32,000	2
CSA[g]	Bar stock	3678A2	2200	1	A.C. to 1400° F	1400	24	1200	10	147,500	62,850	15	300	38,000	2	33,000	2
CSA[g]	Bar stock	3678A2	2050	2	A.C. to 1400° F	1400	24	1200	10	139,600	70,150	22	281	44,000	19	34,000	15
CSA[g]	Bar stock	3678A2	2050	2	A.C. to 1400° F	1400	24	1200	20	141,500	72,250	13	295	44,000	19	33,000	10
[i]19-9DL	Disc	B10429	(j)	(j)	(j)	----	--	----	---	104,700	39,275	30	202-208	40,000	27	34,000	16
[k]19-9DL	Contour disc (EX044)	B11728	2150	2	W.Q.	----	--	1250	(l)	119,600	70,500	26	246-253	47,000	3	38,500	1
[k]19-9DL	Contour disc (EXC46)	B11728	2150	2	W.Q.	----	--	1650	(l)	102,500	39,000	34	200-223	36,500	20	32,000	14
[m]Low-carbon N-155	Disc	A11534	(j)	(j)	(j)	----	--	----	---	118,290	58,750	35	211-255	55,000	12	42,000	10
Timken[n]	Contour disc (8451)	H-4315	(j)	(j)	(j)	----	--	1200 to 1300	(l)	122,780	76,400	14	250-261	45,500	18	34,000	10
Timken[n]	Contour disc (03B-441)	13060	2150	2	W.Q.	----	--	1250	(l)	135,750	81,000	20	269-299	44,000	2	34,000	3
Timken[n]	Contour disc (81509)	H-4684	(j)	(j)	(j)	----	--	1275	(l)	123,875	72,500	18	248-267	49,000	30	34,000	30

[a]All these materials were given a final stress-relief treatment at 1200° F.

[b]Chemical composition (percent) of CSA alloy heats:

Form	Heat number	C	Mn	Si	Cr	Ni	Mo	W	Cb
Discs (5 and 6)	1X2280	0.42	4.47	0.41	18.06	5.20	1.30	1.20	0.28
Disc (hot-forged)	1X2218	.25	4.14	.25	18.52	5.76	1.46	1.51	.95
Bar stock	3678A2	.42	4.17	.55	18.04	5.13	1.41	1.29	.59

[c]A.C. air-cooled.
W.Q. water-quenched.

[d]Time of solution treatment not known.

[e]See reference 2.

[f]As-forged 2150° F to 1400° F.

[g]Previous unpublished data.

[h]Hot-rolled.

[i]See reference 1.

[j]Hot-forged.

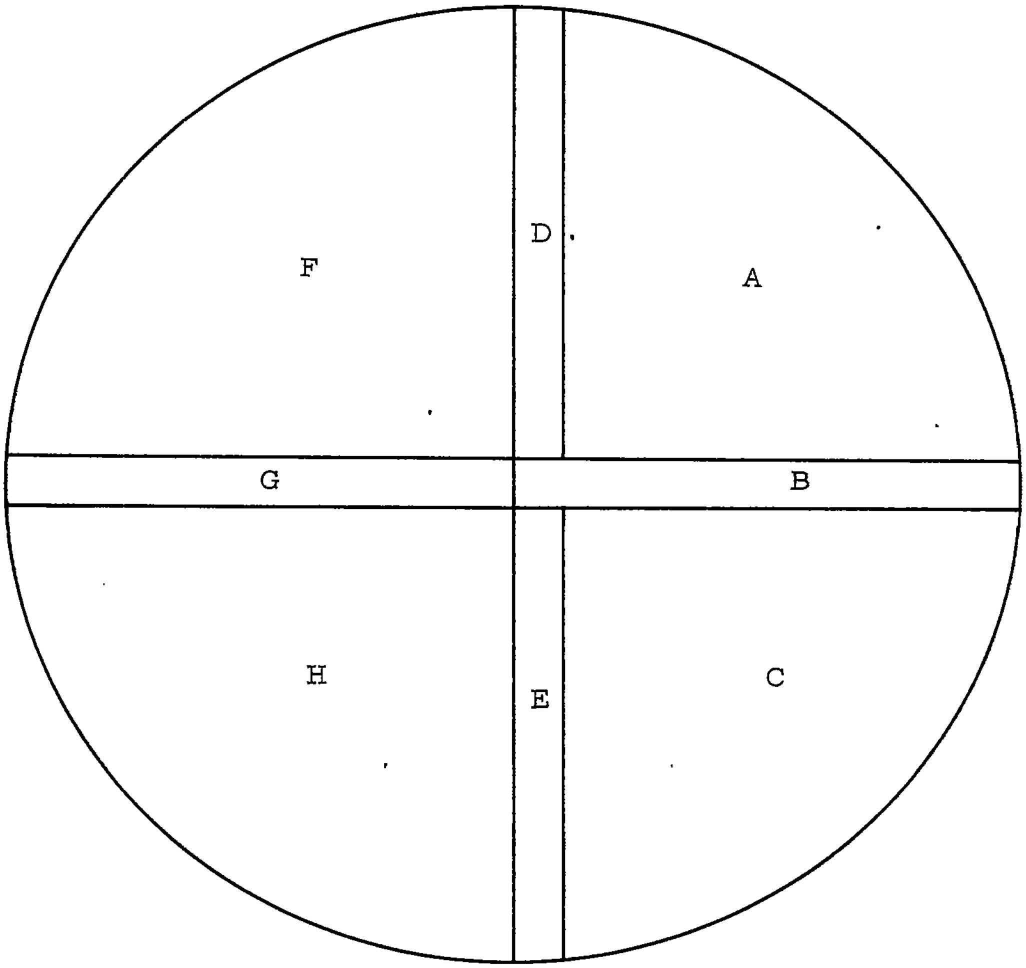
[k]See reference 6.

[l]Exact amount of hot-cold reduction not known.

[m]See reference 3.

[n]See reference 4.

NACA

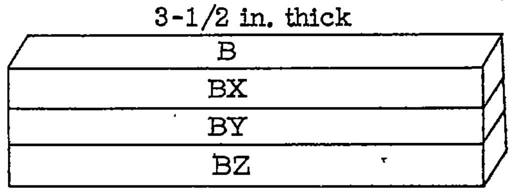


Coupons Received for Testing

Disc 5: solution-treated; hot-cold-worked
- 5B X, Y, and Z
- 5D X, Y, and Z
- 5E X, Y, and Z
- 5G X, Y, and Z

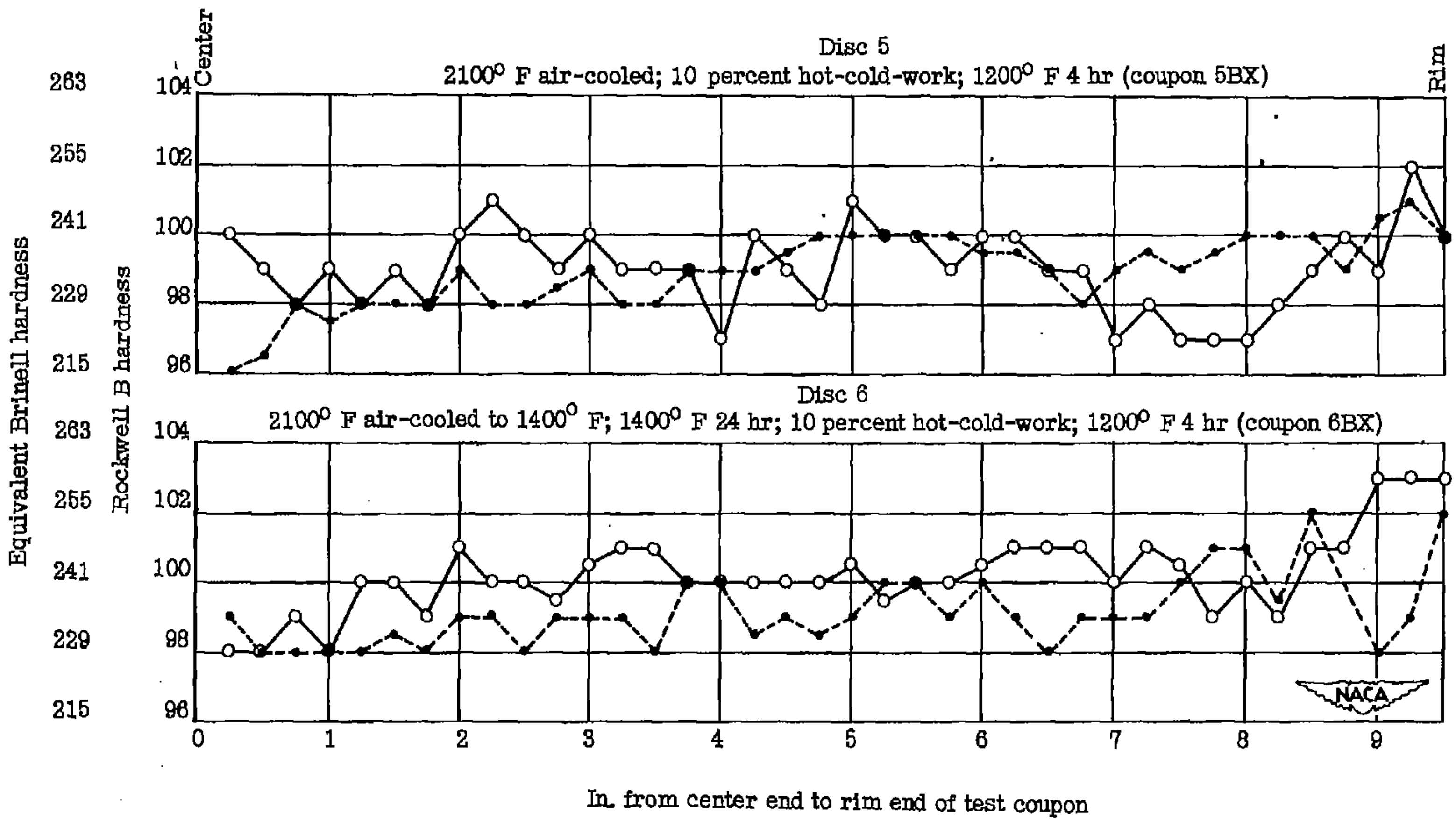
Disc 6: solution-treated; aged; hot-cold-worked
- 6B X, Y, and Z
- 6D X, Y, and Z
- 6E X, Y, and Z
- 6G X, Y, and Z

Disc dimensions: 20-in. diameter by 3-1/2 in. thick



Numbering of coupons

Figure 1.- Diagram showing location of test coupons in large discs of CSA alloy.

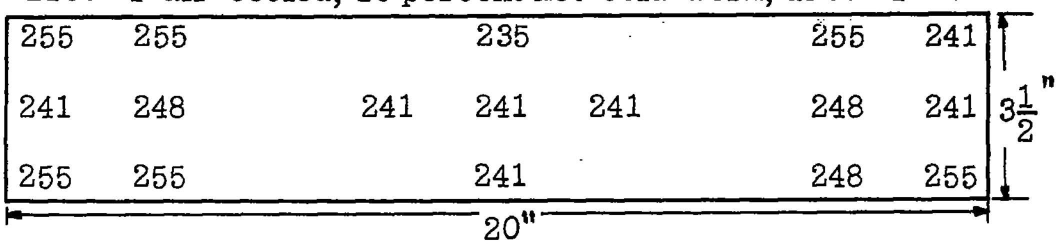


o Surface exposed to forging
● Surface next to Y- or center plane

Figure 2.- Variation in hardness from center to rim of large discs of CSA alloy.

Disc 5

2100° F air-cooled; 10 percent hot-cold-work; 1200° F 4 hr



Disc 6

2100° F air-cooled to 1400° F; 1400° F 24-hr; 10 percent hot-cold-work; 1200° F 4 hr

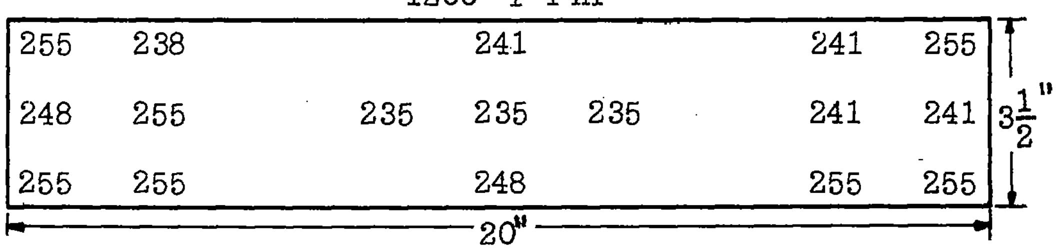


Figure 3.- Brinell hardness survey on large discs of CSA alloy. (Data from Crucible Steel Company of America.)

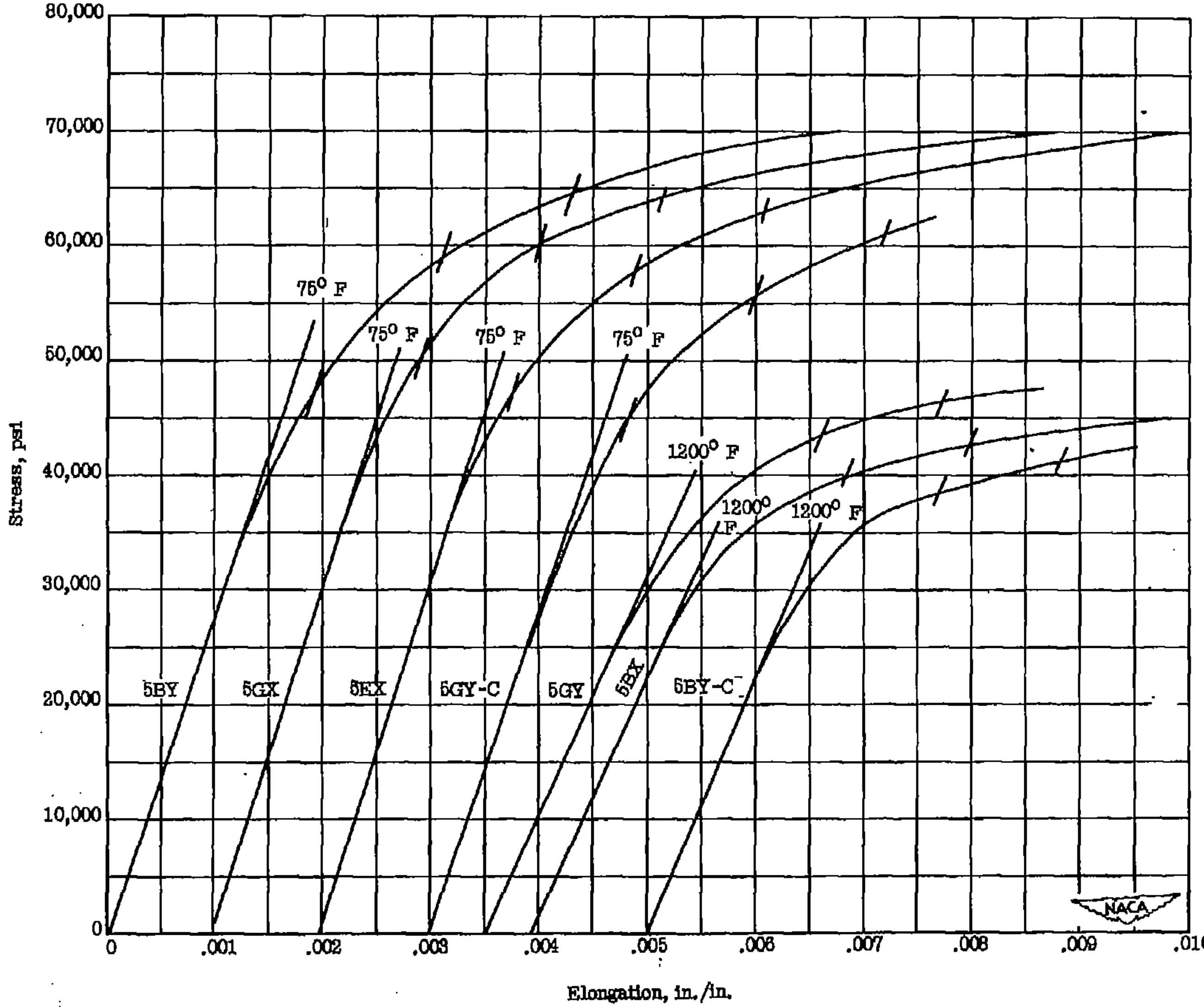


Figure 4.- Stress-strain curves for short-time tensile tests on disc 5 of CSA alloy.

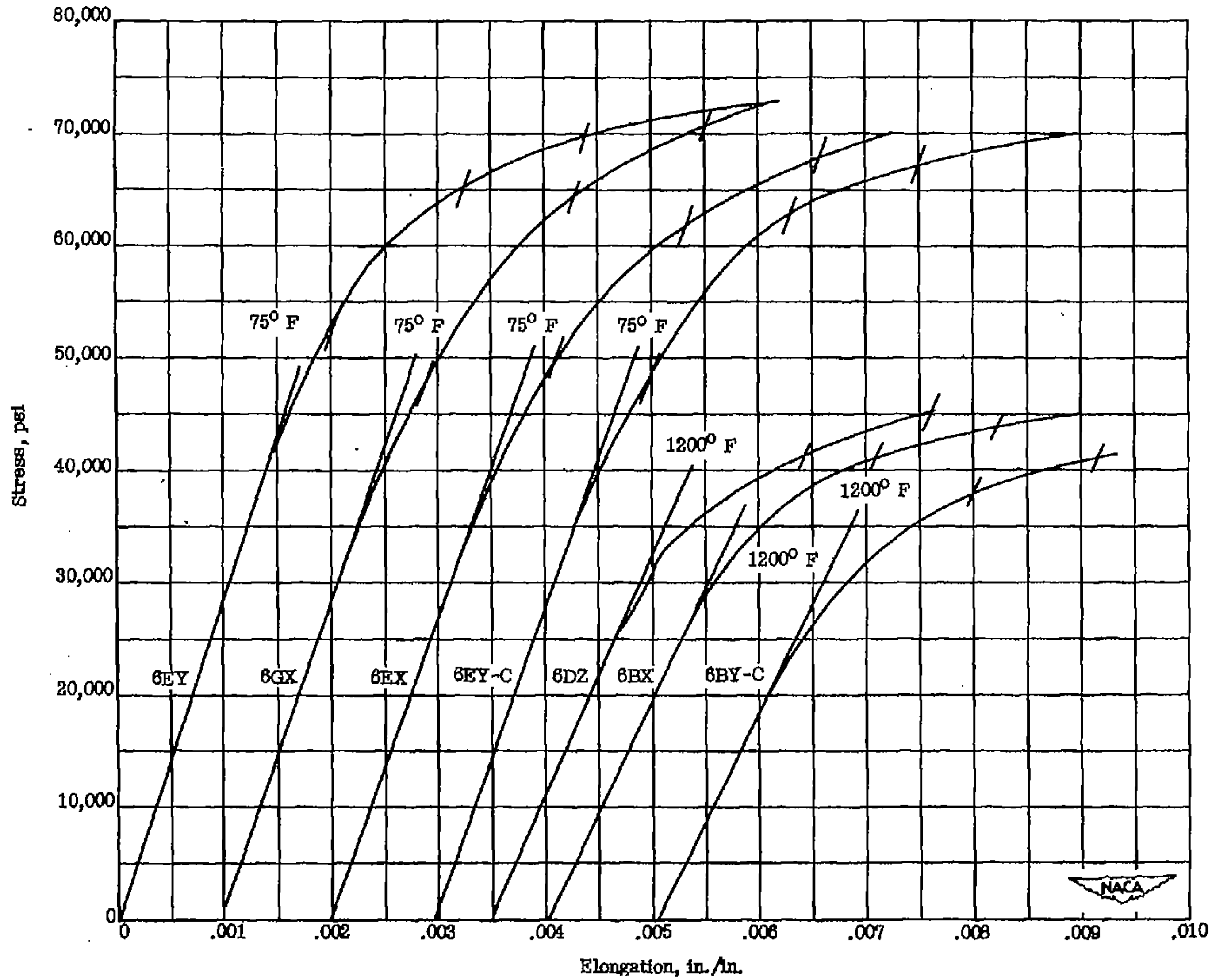
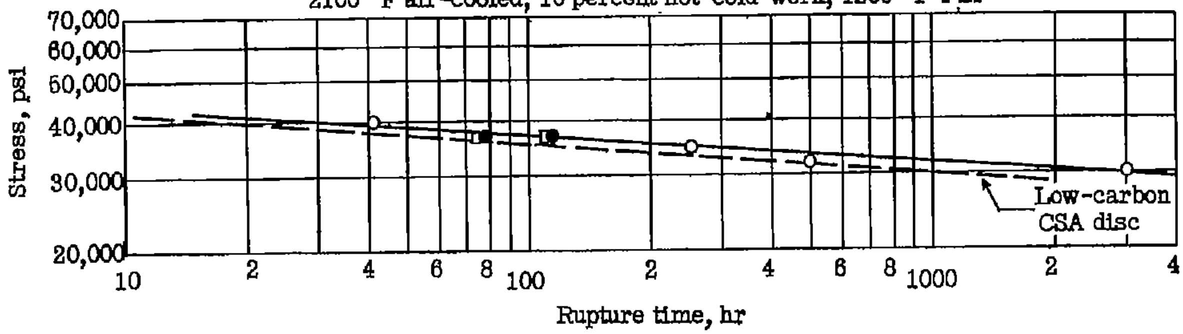


Figure 5.- Stress-strain curves for short-time tensile tests on disc 6 of CSA alloy.

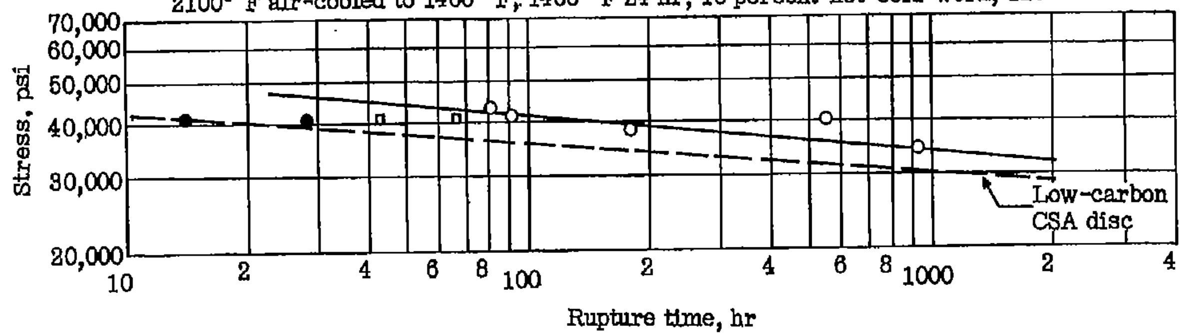
High-carbon CSA disc 5

2100° F air-cooled; 10 percent hot-cold-work; 1200° F 4 hr



High-carbon CSA disc 6

2100° F air-cooled to 1400° F; 1400° F 24 hr; 10 percent hot-cold-work; 1200° F 4 hr



Location of specimen in disc

○ Center radial specimen near rim
● Surface radial specimen near rim
□ Center radial specimen near center
— — — Low-carbon CSA alloy forged disc. (See reference 2.)

Figure 6.- Curves of stress against rupture time at 1200° F for discs of CSA alloy.

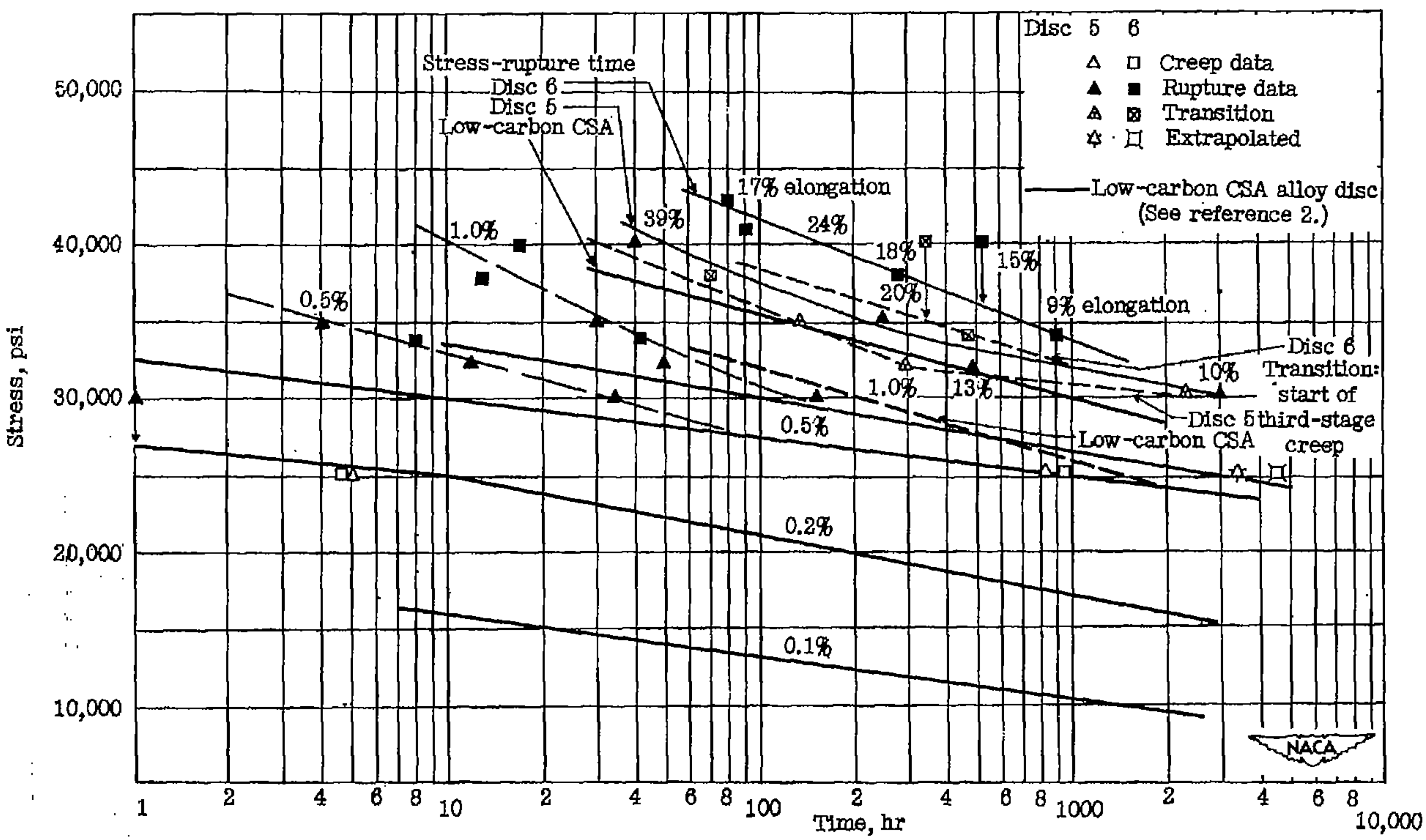
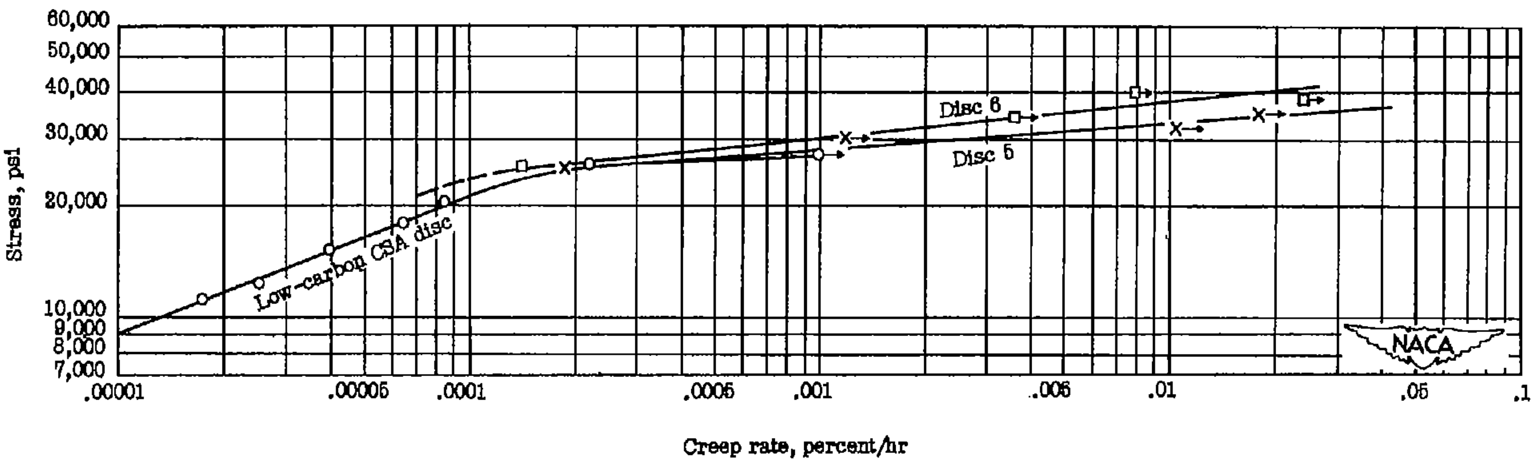
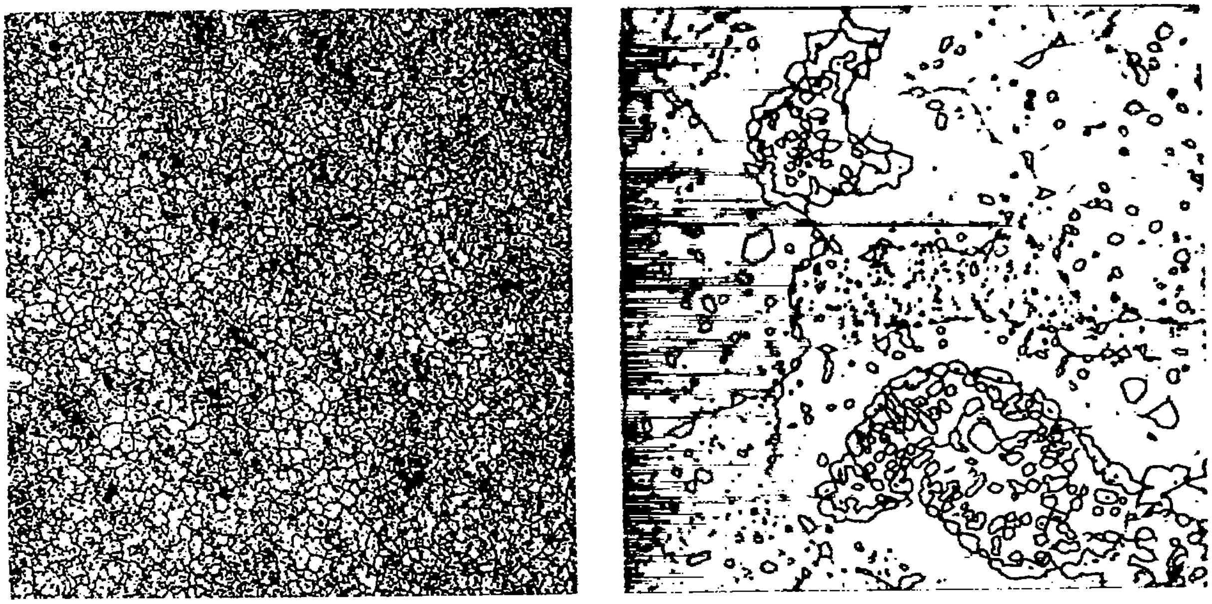


Figure 7.- Curves of stress against time for total deformation at 1200° F for discs of CSA alloy.



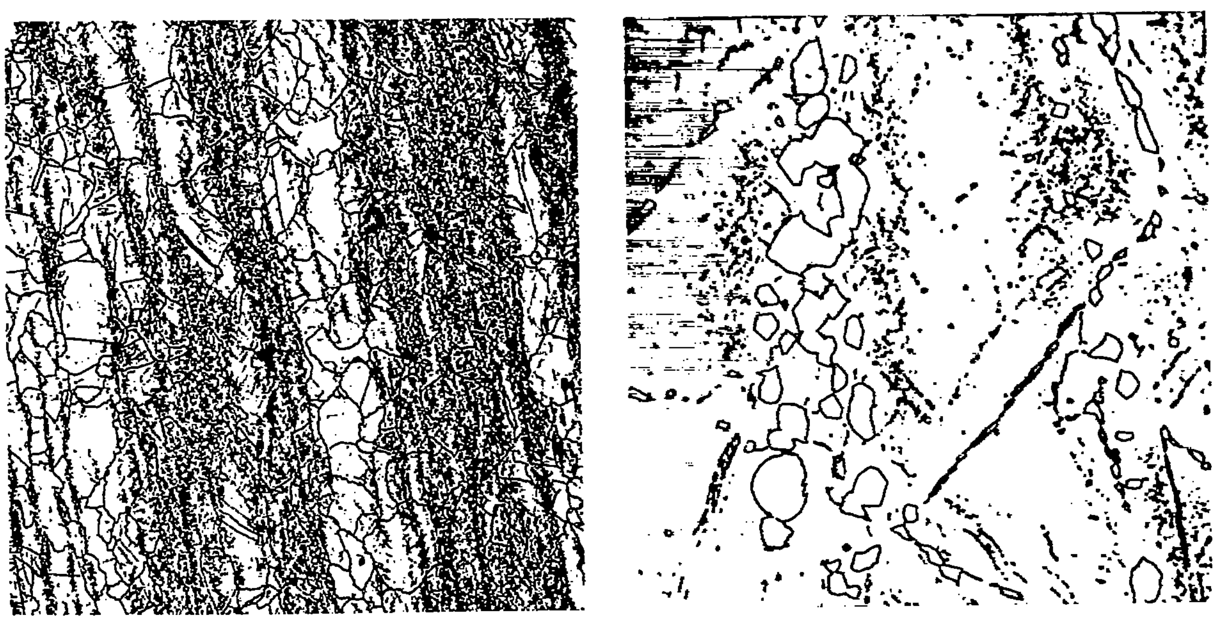
	Disc	Treatment
×	High-carbon 5	2100° F air-cooled; 10 percent hot-cold-work; 1200° F 4 hr
□	High-carbon 6	2100° F air-cooled to 1400° F, held 24 hr; 10 percent hot-cold-work; 1200° F 4 hr
○	Low-carbon	Forged from 2150° F to 1400° F; 1200° F 4 hr. (See reference 2.)
⟶	Test entered third-stage creep	

Figure 8.- Curves of stress against creep rate at 1200° F for discs of CSA alloy. (All data at stresses above 27,000 psi from rupture tests.)



100X 1000X

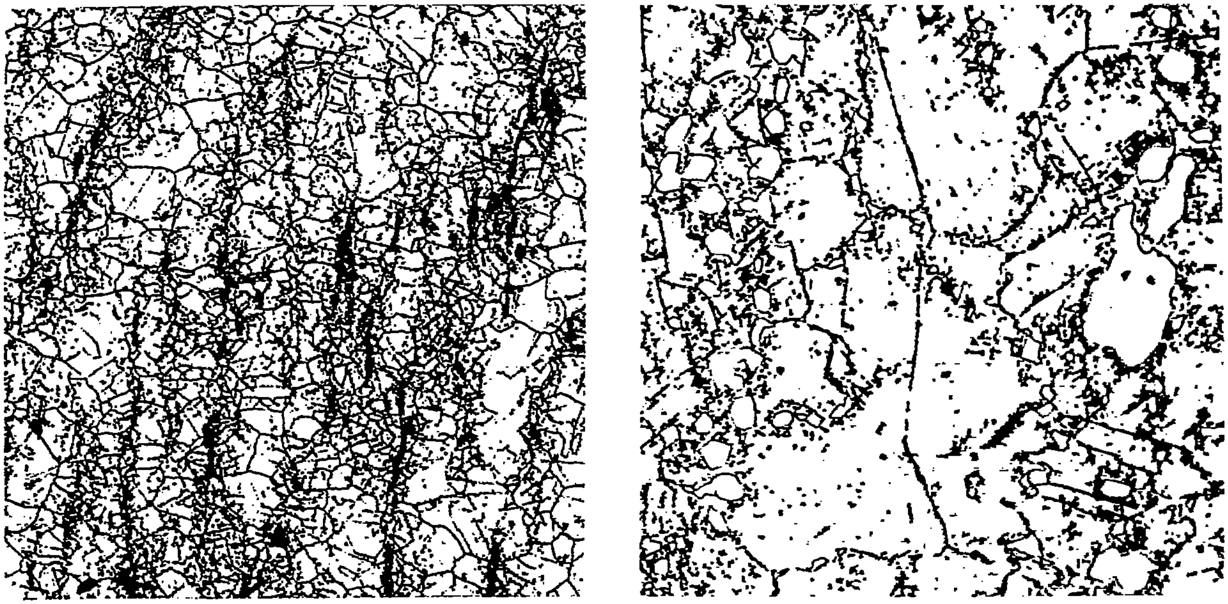
(a) Radial section near rim of disc in Y-plane.



100X 1000X

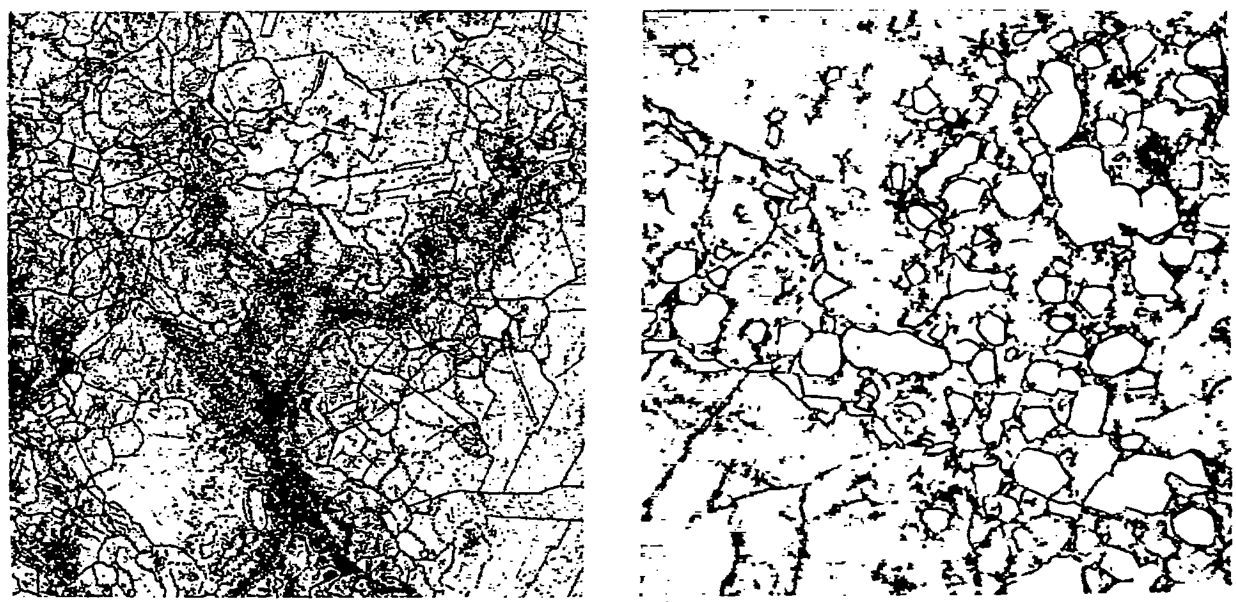
(b) Radial section near center of disc in Y-plane.

Figure 9.- Original microstructure of disc 5 of CSA alloy. (Disc treatment: 2100° F air-cooled; 10 percent hot-cold-work; 1200° F 4 hr.)



100X 1000X

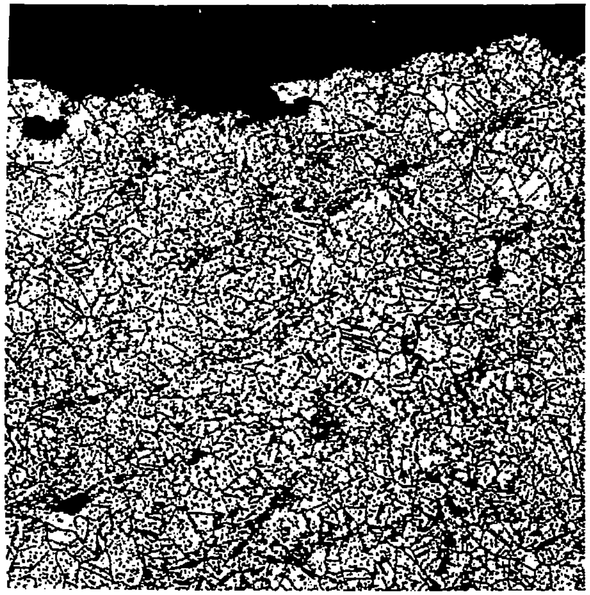
(a) Radial section near rim of disc in Y-plane.



100X 1000X

(b) Radial section near center of disc in Y-plane.

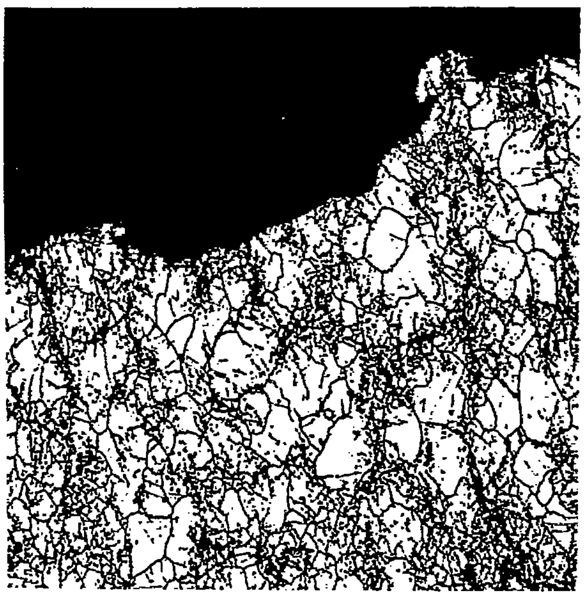
Figure 10.- Original microstructure of disc 6 of CSA alloy. (Disc treatment: 2100° F air-cooled to 1400° F; 1400° F 24 hr; 10 percent hot-cold-work; 1200° F 4 hr.)



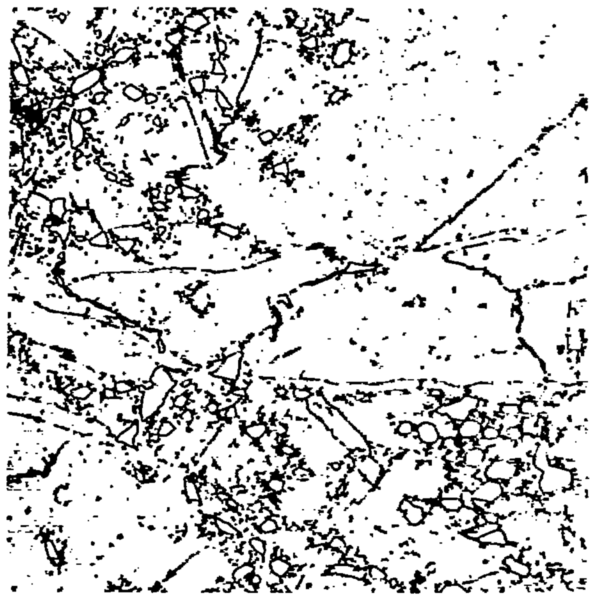
Fracture - 100X

Interior - 1000X

(a) Disc 5: specimen 5DY; 3037 hours for rupture under 30,000 psi.



Fracture - 100X



Interior - 1000X

(b) Disc 6: specimen 6BY; 908 hours for rupture under 34,000 psi.

Figure 11.- Microstructures of completed 1200° F rupture specimens of discs of CSA alloy.